Charge Transport in High-Energy Hadron Collisions

Paul Stankus

Oak Ridge National Laboratory, Oak Ridge, TN 37831

Abstract. Precise measurement of net electrical charge density can reveal the transport of quarks in high-energy p+p or A+A collisions. Such measurements could shed interesting light on the "baryon anomaly" observed at RHIC, on the existence of baryon junctions, and on the general questions of initial stopping and transport in hadronic collisions. Constraints which can be placed on charge transport from existing RHIC data are examined, and other possible future measurements are discussed.

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THE QUESTION OF STOPPING

Inelastic hadron-hadron collisions exhibit some degree of *stopping*, defined very generally as whenever a conserved quantity, such as energy, net charge or net baryon number, is initially carried by incoming beam particles but in the final state is carried by secondary particles at intermediate rapidities. Since pQCD cannot rigorously describe the "bulk" of particles produced at low low-p_T in which they can reside, the transport of conserved quantities is a fundamental question of non-perturbative QCD.

One of the most provocative results from the RHIC A+A program is the conclusion that local thermal equilibrium is obtained very quickly in the created matter [1]; the mechanism remains unclear, but initial thermalization is clearly intimately connected with initial energy stopping. The anomalously high baryon/pion ratio observed at mid-p_T in central RHIC A+A collisions [2] is – presumably – similarly connected to the mechanism of initial baryon stopping/transport.

Quark versus Baryon Transport

For these reasons (and others) it is of interest to measure both net baryon number stopping and net valence quark stopping in RHIC A+A collisions. And, these should be measured separately! Contrary to a naïve expectation, baryon number transport and valence quark transport are not necessarily tied together; an example is in the theory of baryon junctions [3], as described in Figure 1. Net baryon stopping has been measured at RHIC through the antiproton/proton ratio [4] and the high net baryon density at mid-rapidity has excited interest in the baryon junction mechanism [4,5].

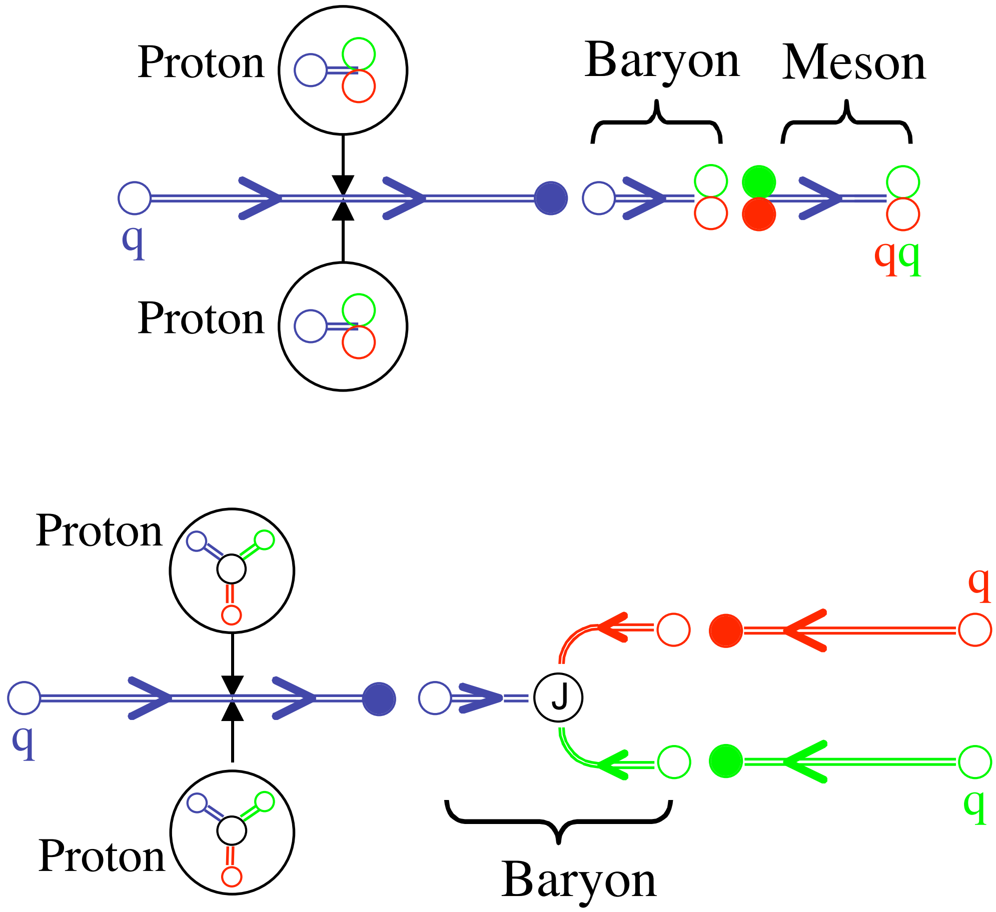

FIGURE 1. Two descriptions of baryon formation during color string fragmentation. **Upper:** A proton-proton collision leads to the creation of a color string stretched between a quark (blue) from one proton and a diquark (red+green=antiblue) in the other (the arrows indicate the direction of the color field). A diquarik-antidiquark breaking results in a meson at the string's end, and a quark-antiquark breaking results in a baryon in the next position. **Lower:** In the baryon junction picture the initial colored string is stretched between three quarks (red, blue and green) all connected to the junction. There are no diquarks in this picture, and three quark-antiquark breakings adjacent to the junction produce a baryon in the middle of the string while the valence quarks remain at high rapidities.

We can measure valence quark stopping independently by measuring net electrical charge in final-state particles in some range of phase space. One useful observable is the ratio of net charge in mesons to the net charge in baryons, $(\pi^{\mathrm{Net}}+K^{\mathrm{Net}})/p^{\mathrm{Net}}$. We can predict its value in the two extremes (i) no valence quarks stop, and (ii) all the net baryons are made from stopped valence quarks:

$$\begin{aligned} \frac{\pi^{\mathrm{Net}}+K^{\mathrm{Net}}}{p^{\mathrm{Net}}} &= -1.00 \quad \text{No valence quark stopping} \\ &= \frac{Z}{A}\left(\frac{n^{\mathrm{Net}}}{p^{\mathrm{Net}}}+\frac{\Lambda^{\mathrm{Net}}}{p^{\mathrm{Net}}}\right)-\left(1-\frac{Z}{A}\right) \quad \text{Full valence quark stopping} \end{aligned} \tag{1}$$

(The result predicted by a baryon junction model is intermediate between the two.)

With knowledge of Λ/p ratios and some reasonable assumptions for n(bar)/p(bar) we can estimate the full valence quark stopping result for $(\pi^{Net}+K^{Net})/p^{Net}$ to be in the range 0.0-0.2 for central Au+Au collisions at RHIC. We can calculate the experimental value from the measured particle densities [4,6] and particle/antiparticle ratios [6,7] in those collisions:

TABLE 1. Particle/antiparticle ratios at mid-rapidity in central Au+Au at RHIC

Ratio	Value(s)	Sources	Combined Result
pbar/p		All experiments	0.74±0.03
K^-/K^+	0.95±0.05	BRAHMS	0.95±0.032
	0.95±0.042	PHOBOS	
π^-/π^+	1.01±0.04	BRAHMS	1.022±0.017
	1.025±0.019	PHOBOS	
$(\pi^{Net}+K^{Net})/p^{Net}$			-0.60±0.082

We can see that the result of -0.60±0.082 for $(\pi^{Net}+K^{Net})/p^{Net}$ is, unfortunately, unable to distinguish between the no-stopping result of –1.0 and the full-stopping result of 0.0-0.2. The uncertainty in the final result is completely dominated by the uncertainty on the π^-/π^+ ratio, about 2% in the published data. If this could be reduced, either through a closer re-analysis or a new experimental measurement, to a level of 0.5% or better, then a significant statement about valence quark stopping in RHIC collisions could be made. Though not discussed here, the corresponding charge stopping results from current RHIC p+p and d+Au data are similarly inconclusive, while ISR data remains to be examined.

Another approach to measuring valence quark stopping would be to look at the change in the positive/negative ratio in secondaries when the charge, but not the baryon number, of the beams is changed; for example distinguishing between p+A and n+A in d+A collisions, or more exotically comparing $^{96}Zr+^{96}Zr$ with $^{96}Ru+^{96}Ru$.

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